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Classifying Forest Susceptibility to Gypsy Moth Defoliation

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Classifying Forest Susceptibility to Gypsy Moth Defoliation

by David R. Houston and Harry T. Valentine[1]

Introduction

Over three decades ago, an excellent description was presented of forests susceptible or resistant to gypsy moth defoliation in the Northeast, especially in New England (Bess and others 1947). The recent spread of the insect into new and different forest situations has created a need for ways to predict the susceptibilities of forests that have yet to encounter gypsy moth defoliation. In this handbook, we describe susceptible and resistant New England stands and present an objective method for predicting the susceptibility of stands to defoliation.

Any oak forest within the range of the gypsy moth, regardless of its relative susceptibility, may be defoliated during periods when outbreaks occur over vast areas. Forests resistant to defoliation usually are defoliated only during such outbreaks, while forests susceptible to defoliation are defoliated more frequently. In interim periods between outbreaks, defoliation may occur in susceptible stands and it has been hypothesized that some of these may serve as foci from which outbreaks emanate (Houston and Valentine 1977).

Many interrelated factors influence forest susceptibility. Most important is the composition of the forest because gypsy moths defoliate some tree species preferentially. Other important factors include the exposure and moisture conditions of the sites the trees are growing in, the nature and degree of disturbance the forest is exposed to, and the length of time that the forest and insect have been interacting.

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Stand Composition

It is well known that the leaves of some tree species are most preferred as food by the gypsy moth; some are less preferred but are eaten readily when the most preferred are scarce; others are seldom, if ever, eaten (table 1). Most preferred are leaves of oak species, especially white oak (*Quercus alba*), chestnut oak (*Q. prinus*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), and northern red oak (*Q. rubra*).

The foliage of some tree species is suitable as food for first-instar gypsy moth larvae, whereas that of others, hemlock, for example, is eaten only by older larvae. Hemlock stands, therefore, are unlikely to be severely defoliated unless sufficient numbers of other tree species, such as oaks, are present to sustain the insects during the first few weeks of life.

Stands rich in aspen or gray birch were among the most susceptible forests in the Northeast during the early part of this century. It has been suggested that these kinds of stands are highly susceptible not because aspen or birch are especially preferred but because of the disturbances that give rise to this forest type.

Stand Disturbance

There is considerable evidence that some outbreaks of gypsy moths are associated with disturbance of the forest. Although this association is not entirely understood, it probably involves both long-term effects favoring species that satisfy the insect's food requirements and short-term effects on tree conditions that either satisfy the insect's habitat requirements or reduce the chances for its encounter with natural enemies. Disturbance may set back forest development or hold it in check. Disturbance often favors the occurrence and persistence of highly preferred food species and, by injuring trees or slowing their growth, creates protected places on the trees for gypsy moths to rest, pupate, and oviposit. Such refuges often are well above the forest floor, out of reach of many important predators of the gypsy moth.

Observations over the past 100 years have shed some light on the relationship of continual stress on forests by adverse environmental factors and the occurrence of gypsy moth. Throughout the first quarter of this century, forests of eastern New England were disturbed, more or less continually, by human activities. Repeated and heavy logging and frequent, severe fires were common events, as were severe, sustained insect outbreaks.

For many reasons, people-related disturbances have been fewer from 1920 to the present. Existing forests were left to develop, and many "new" forests have emerged on lands withdrawn from agriculture. This change generally has been accompanied by less frequent and less severe outbreaks, although certain forests have continued to harbor the gypsy moth and have been defoliated repeatedly.

In New England, these susceptible forests frequently are on dry ridges and steep upper slopes that have shallow soils and on sandy plains that have deep, ex-

cessively drained soils (figs. 1-2). Such stands typically develop slowly because moisture is limited. Trees on these sites often are species highly preferred as food by gypsy moth, and because of their repeated exposure to fires and storms, these trees provide abundant refuges for the insect.

By contrast, forests developing relatively free of environmental disturbance on sites where moisture is not limited generally are resistant to gypsy moth. Such forests tend to be on mesic ridges, slopes, and bottom lands, and they commonly contain mixtures of preferred and nonpreferred food species. The trees are fast growing and straight and bear relatively few refuges for gypsy moths (figs. 1 and 3).

In New England, many stands on mesic sites are changing from susceptible to resistant as their natural development is accompanied by decreases of highly preferred species and by proportionate increases of less preferred species. A stand that consists of a sizable proportion of highly preferred food species can be rendered susceptible by disturbances that open up the stand and once again favor the more light-demanding food species preferred by the gypsy moth. Such disturbance also can render the stand less suitable for ground-inhabiting predators of the gypsy moth by removing or drying out the litter and soil and by creating aboveground protective refuges from the predators for the gypsy moth on the trees.

The reentry of people into the forests of the Northeast (especially resistant forests) has demonstrated anew the close association between disturbance and gypsy moth outbreaks. Disturbances to stands and trees associated with urbanization—housing developments, recreational facilities, and construction and maintenance of roads and powerlines—often seem to precede outbreaks. It is possible that actions of people affect forested backyards as the forces of nature affect forests on adverse sites. Certainly, opening up the forest to make lawns, raking up forest litter, and keeping pets help discourage natural predators of the insect. Walls, woodpiles, tree houses, tacked-up signs, and other objects within the backyard forest create many suitable refuges for gypsy moth.

Table 1—*Breakdown of encountered tree species into food-preference classes*

I. Most Preferred

Acer negundo (boxelder)
Alnus spp. (alder)
Betula papyrifera (paper birch)
B. populifolia (gray birch)
Crataegus spp. (hawthorn)
Larix laricina (tamarack)
Liquidambar styraciflua (sweetgum)
Malus spp. (apple)
Populus grandidentata (bigtooth aspen)
P. tremuloides (quaking aspen)
Quercus alba (white oak)
Q. bicolor (swamp white oak)
Q. coccinea (scarlet oak)
Q. ellipsoidalis (northern pin oak)
Q. falcata (southern red oak)
Q. ilicifolia (bear oak)
Q. imbricaria (shingle oak)
Q. macrocarpa (bur oak)
Q. marilandica (blackjack oak)
Q. muehlenbergii (chinkapin oak)
Q. palustris (pin oak)
Q. phellos (willow oak)
Q. prinus (chestnut oak)
Q. rubra (northern red oak)
Q. stellata (post oak)
Q. velutina (black oak)
Salix spp. (willow)
Tilia americana (American basswood)

II. Intermediate

Acer pensylvanicum (striped maple)
A. rubrum (red maple)
A. saccharinum (silver maple)
A. saccharum (sugar maple)
Aesculus glabra (Ohio buckeye)
Aesculus octandra (yellow buckeye)
Amelanchier canadensis (serviceberry)
Asimina triloba (paw paw)
Betula alleghaniensis (yellow birch)
B. lenta (sweet birch)
Carpinus caroliniana (American hornbeam)
Carya cordiformis (bitternut hickory)
C. glabra (pignut hickory)
C. ovata (shagbark hickory)
C. tomentosa (mockernut hickory)
Castanea dentata (American chestnut)
C. pumila (Allegheny chinkapin)
Celtis occidentalis (hackberry)
Cercis canadensis (eastern redbud)
Cornus florida (flowering dogwood)
Diospyros virginiana (common persimmon)
Fagus grandifolia (American beech)
Hamamelis virginiana (witchhazel)
Juglans cinerea (butternut)
J. nigra (black walnut)
Magnolia acuminata (cucumbertree)
Nyssa sylvatica (black tupelo)
Ostrya virginiana (eastern hophornbeam)
Oxydendrum arboreum (sourwood)
Pinus banksiana (jack pine)
P. echinata (shortleaf pine)
P. pungens (table-mountain pine)
P. resinosa (red pine)
P. rigida (pitch pine)
P. strobus (eastern white pine)
P. sylvestris (Scotch pine)

P. virginiana (Virginia pine)
Populus deltoides (eastern cottonwood)
Prunus pensylvanica (pin cherry)
P. serotina (black cherry)
P. virginiana (chokecherry)
Sassafras albidum (sassafras)
Tsuga canadensis (eastern hemlock)
Ulmus americana (American elm)
U. rubra (slippery elm)

III. Least Preferred

Abies fraseri (fraser fir)
Acer spicatum (mountain maple)
Fraxinus americana (white ash)
F. nigra (black ash)
F. pennsylvanica (green ash)
F. quadrangulata (blue ash)
Ilex opaca (American holly)
Juniperus virginiana (eastern redcedar)
Liriodendron tulipfera (yellow-poplar)
Morus rubra (red mulberry)
Picea rubens (red spruce)
Pinus sylvestris (Scotch pine)
Platanus occidentalis (American sycamore)
Rhus spp. (sumac)
Robinia pseudoacacia (black locust)

Figure 1.—Susceptible and resistant forests of New England. Susceptible forests characteristically grow on dry sites such as rocky ridges (left) or deep sands (right). In many cases, they have been disturbed, sometimes frequently, by fires, wind, snow, or ice storms. The trees in these forests (mainly dry-site oaks) often are slow growing, small, and scrubby, and have abundant structural features such as bark flaps, deep bark fissures, and holes or wounds that offer favored refuges for gypsy moth. The open nature of susceptible forests encourages growth of plants such as blueberry and huckleberry, bracken, sweetfern, grasses, and sedges. Leaf litter usually is shallow or lacking, and on the ridge stands, surface rocks or exposed ledges are common. Resistant stands (center) characteristically grow on well-drained deep loam soils where moisture is not limited. They usually have been relatively free from recent disturbance, are well stocked, and contain mixtures of species. Resistant stands can contain trees of highly preferred species, but these trees, like their less preferred associates, will have good growth rates and are relatively free of the gypsy moth refuges so common on their adverse-site counterparts. Understory plants in resistant forests in New England include such species as wild sarsaparilla, maple-leafed viburnum, and woodland ferns. Resistant stands have deep litter layers that provide favorable habitat for ground beetle and small mammal predators of gypsy moth.

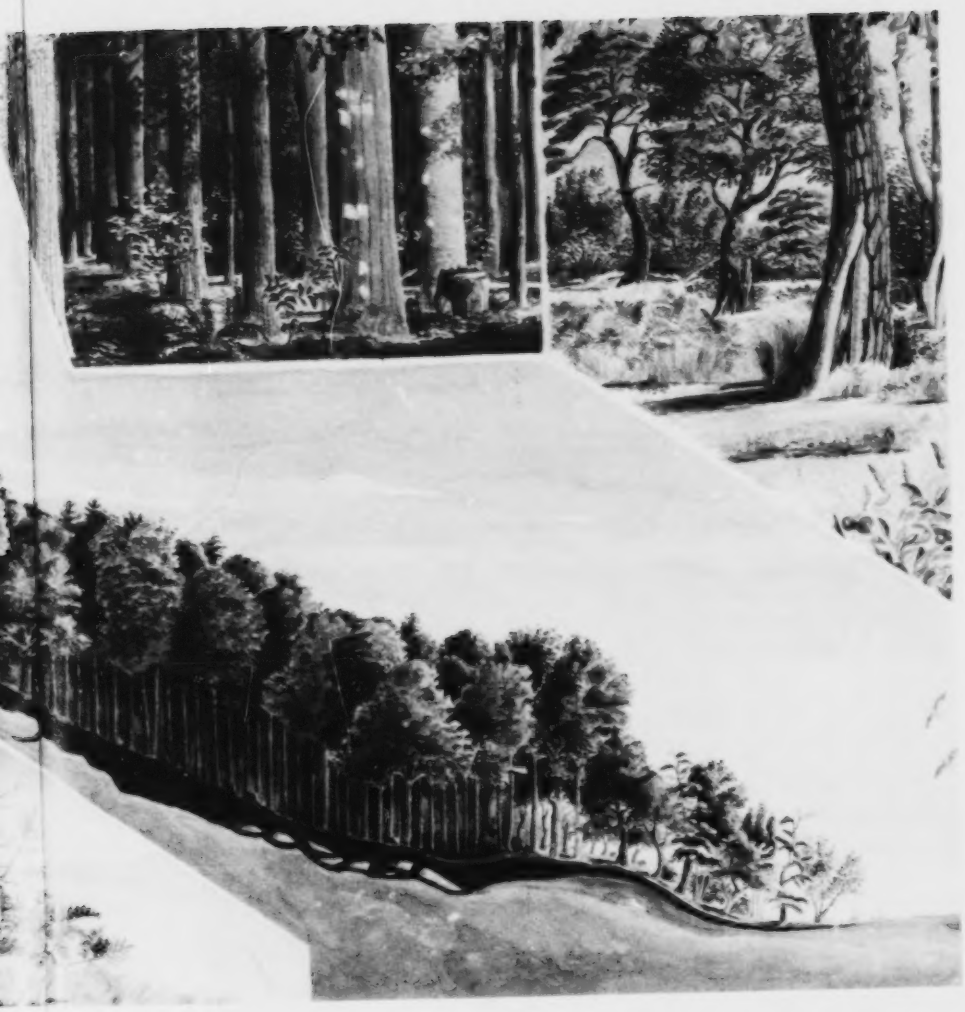

Figure 2.—Winter and autumn view of susceptible forest: (A) and (B) Bryant Mountain near Middlebury, VT; (C) a mountain near Sandgate, VT; (D) Cape Cod, near Harwick, MA.

Figure 3.—Winter and summer views of a resistant oak forest near Madison, CT.

Determining Susceptibility or Resistance

The susceptibility of a stand to gypsy moth defoliation can be estimated subjectively from an examination of the abundance and size of potential gypsy moth refuges (fig. 4) on the trees, the composition of the stand, its stocking, the degree of recent disturbance, and the physiography and exposure of the site. As was noted, stands susceptible to defoliation generally are on dry or disturbed sites and contain high proportions of preferred tree species with abundant refuges for gypsy moths. By contrast, stands that are resistant to defoliation generally are on mesic sites and contain mixtures of preferred, intermediate, and least preferred tree species with relatively few refuges. Resistant stands generally are well stocked, fast growing, and free from recent disturbance. These subjective estimates are based on long-recognized insect/forest associations in the Northeastern United States. As the gypsy moth invades new territory, where perceptions of resistant and susceptible forests are lacking, more objective means of estimating susceptibility are needed.

Objective predictions of the susceptibilities of stands to defoliation can be made with either of two discriminant functions reported by Valentine and Houston (1984). One discriminant function uses only variables that can be calculated from diameter measurements of preferred tree species. The second function, which is more accurate, requires knowledge of the presence or absence of deep bark fissures or bark flaps on the lower boles of preferred tree species.

The discriminatory variables used in the discriminant functions are:

x_1 = sum of diameters (inches) of preferred host trees per acre
x_2 = basal area (ft^2) of preferred host trees per acre
x_3 = sum of diameters (inches) per acre of preferred host trees with one or more deep (≥0.5 inch) bark fissures
x_4 = sum of diameters (inches) per acre of preferred host trees with one or more bark flaps
x_5 = quadratic mean diameter (inches) of preferred host trees.

In all cases, diameter at breast height (d.b.h.) (4.5 feet) is measured, and only trees that have diameter greater than 2.5 inches are counted. Deep bark fissures and bark flaps must occur between the ground and 6 feet up the bole. A bark flap must open from below and be ≥0.5 inch wide.

If values for x_3 and x_4 are not available, the stand's susceptibility can be identified by use of the following discriminant function (equation 1):

$$Y_1 = 6.2348 - 0.1541x_1/x_2 - 0.01099x_1/x_5 \quad (1)$$

A positive discriminant score ($Y_1>0$) predicts that a stand is resistant to gypsy moth defoliation; a nonpositive score ($Y_1\leq 0$) predicts that a stand is susceptible.

Figure 4.—(A) Storm-damaged tree on a Vermont mountain ridge bears many of the structural features used by gypsy moths: (B) large, low, dead branches; (C) bark flaps; (D) dead sprout stubs; (E) deep bark fissures; (F) holes and wounds; and (G) crook or sweep. Egg masses or pupal cases are found in many of these refuges for gypsy moths.

If values for x_3 and x_4 are available, the susceptibility of the stand to defoliation can be identified by calculating the discriminant score (Y_2) by use of the following discriminant function (equation 2):

$$Y_2 = 14.799 - 0.4245x_1/x_2 - 0.004962x_3 - 0.005379x_4 \quad (2)$$

Again, positive scores predict resistance; nonpositive scores predict susceptibility. In New England, identifications based on equation 1 should be correct more than 80 percent of the time. Identifications based on equation 2 should be correct more than 90 percent of the time. Outside New England, error rates for the functions are unknown.

In practice, we usually do not use a discriminant function to identify the susceptibility of a whole stand. Instead, we identify the susceptibility of a fixed area or a variable radius plot selected at random. In the former case we randomly select one or more plots whose combined area equals z ac (we suggest $z \geq .1$ ac) in the stand. We denote the d.b.h. of the ith of m preferred host trees in the plot(s) as d_i. The discriminatory variables are calculated as:

$$x_1 = \left(\sum_{i=1}^{m} d_i\right) \Big/ z$$

$$x_2 = .005454154 \left(\sum_{i=1}^{m} d_i^2\right) \Big/ z$$

$$x_3 = \left(\sum_{i=1}^{m} d_i u_i\right) \Big/ z$$

$$x_4 = \left(\sum_{i=1}^{m} d_i v_i\right) \Big/ z$$

$$x_5 = \left[\left(\sum_{i=1}^{m} d_i^2\right) \Big/ m\right]^{1/2}$$

where, u_i equals 1 if the ith tree has 1 or more deep bark fissures; otherwise u_i equals 0; v_i equals 1 if the ith tree has one or more bark flaps; otherwise v_i equals 0.

Example

To identify the susceptibility of a variable radius plot we use point sampling. We use a prism or angle gauge with basal-area factor F (feet^2/ac) to select trees from randomly selected points in the stand of interest. If a total of n preferred trees is selected at N points, the discriminatory variables are calculated as:

$$x_1 = 183.346F\left(\sum_{i=1}^{n} 1/d_i\right)\Big/N$$

$$x_2 = nF/N$$

$$x_3 = 183.346F\left(\sum_{i=1}^{n} u_i/d_i\right)\Big/N$$

$$x_4 = 183.346F\left(\sum_{i=1}^{n} v_i/d_i\right)\Big/N$$

$$x_5 = \left\{\left(n/N\right)\Big/\left[\left(\sum_{i=1}^{n} 1/d_i^2\right)\Big/N\right]\right\}^{1/2}$$

A stand in North Stonington, CT, that comprises mixed oaks, hickories, and black birch was sampled for its susceptibility to gypsy moth defoliation. The stand was sampled at a point with a prism with basal-area factor of 10 feet^2/acre, and with a circular plot with radius 33 feet centered at the point.

The data for the point sample were:

Species	*Diameter*	*Deep fissures*	*Bark flaps*
White oak	5.0	0	0
Red oak	8.5	0	0
White oak	13.5	0	0
White oak	16.1	0	1
White oak	14.2	0	0
Red oak	10.4	1	1

The values of the discriminatory variables are:

$$\begin{aligned} x_1 &= 183.3 \times 10 \times (1/5. + 1/8.5 \\ &\quad + 1/13.5 + 1/16.1 + 1/14.2 \\ &\quad + 1/10.4) \\ &= 1137.2 \\ x_2 &= 10 \times 6 = 60.0 \\ x_3 &= 183.3 \times 10 \times (1/10.4) = 176.3 \\ x_4 &= 183.3 \times 10 \times (1/16.1 + 1/10.4) \\ &= 290.1 \\ x_5 &= \{6/(1/5.0^2 + 1/8.5^2 + 1/13.5^2 \\ &\quad + 1/16.1^2 + 1/14.2^2 + 1/10.4^2)\}^{1/2} \\ &= 8.8 \end{aligned}$$

The discriminant score for the stand using equation 1 is

$$\begin{aligned} Y_1 &= 6.2348 - 0.1541 \times 1137.2/60.0 \\ &\quad - 0.01099 \times 1137.2/8.8 \\ &= 1.89 \end{aligned}$$

The discriminant score for the stand using equation 2 is

$$Y_2 = 14.799 - 0.4245 \times 1137.2/60.0 - 0.004962 \times 176.3 - 0.005379 \times 290.1 = 4.32$$

Because the discriminant scores are positive, the stand probably is resistant to defoliation on the basis of the prism sample.

The data obtained in the circular plot centered at the prism point were:

Species	*Diameter*	*Deep fissures*	*Bark flaps*
White oak	5.0	0	0
White oak	5.6	0	0
Chestnut oak	3.7	1	0
White oak	13.5	0	0
Red oak	8.5	0	0
White oak	16.1	0	1
Black oak	4.9	0	0
Scarlet oak	7.5	0	0
Red oak	6.2	1	0
Red oak	10.4	1	1
Red oak	4.2	0	0

The area covered by a plot with radius 33 feet is $\pi 33^2$ feet^2 × 1 acre/43560 feet^2 = 0.0785 acre. The values of the discriminatory variables based on the plot sample are:

$$x_1 = (5.0 + 5.6 + 3.7 + 13.5 + 8.5 + 16.1 + 4.9 + 7.5 + 6.2 + 10.4 + 4.2)/.0785 = 1090.5$$

$$x_2 = .005454 \times (5.0^2 + 5.6^2 + \ldots + 10.4^2 + 4.2^2)/.0785 = 57.6$$

$$x_3 = (3.7 + 6.2 + 10.4)/.0785 = 258.6$$

$$x_4 = (16.1 + 10.4)/.0785 = 337.6$$

$$x_5 = [(5.0^2 + 5.6^2 + \ldots + 10.4^2 + 4.2^2)/11]^{1/2} = 8.7$$

Using equation 1, the discriminant score is

$$Y_1 = 6.2348 - 0.1541 \times 1090.5/57.6 - 0.01099 \times 1090.5/8.7 = 1.94$$

The discriminant score for the stand based on the plot sample using equation 2 is

$$Y_2 = 14.799 - 0.4245 \times 1090.5/57.6 - 0.004962 \times 258.6 - 0.005379 \times 337.6 = 3.66$$

Again, both discriminant functions indicate that the stand is resistant to gypsy moth defoliation.

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